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Technical Letter
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Engineering and Design
USE OF THE U.S. COAST GUARD DIFFERENTIAL GLOBAL POSITIONING SYSTEM AND THE CONTINUOUSLY OPERATING REFERENCE STATION SYSTEM

1. Purpose. This technical letter provides guidance and procedures on the use of the U.S. Coast Guard's (USCG) Radiobeacon Differential Global Positioning System (DGPS) and the National Geodetic Survey's (NGS) Continuously Operating Reference Station (CORS) System. Procedures and equipment required for for U.S. Army Corps of Engineers (USACE) access to these systems are defined.

2. Applicability. This technical letter is applicable to USACE commands having civil works, military construction, and environmental restoration responsibilities.

3. References.

a. USCG Navigation Center (NAVCEN) Web site http://www.navcen.uscg.mil.

b. National Geodetic Survey CORS Web Site http://www.ngs.noaa.gov/CORS/cors-data.html.

c. EM 1110-1-1003, NAVSTAR Global Positioning System Surveying, 1 August 1996.

4. Distribution. Approved for public release; distribution is unlimited.

5. Background.

a. The NAVSTAR Global Positioning System (GPS) is a real-time, all-weather, 24-hour, worldwide, 3-dimensional absolute satellite-based positioning and navigation system developed by the U.S. Department of Defense. This system consists of two positioning services: the Precise Positioning Service (PPS) and the Standard Positioning Service (SPS). PPS was developed for the U.S. military and other authorized users, uses the P(Y)-code on the L1 and L2 carriers, and provides an accuracy of 16 meters. SPS is available to civilian users, uses the C/A-code on the L1

carrier, and provides accuracy of 100 meters.

b. For many applications, absolute positioning does not provide sufficient accuracy. Differential GPS (DGPS) is a technique which can provide relative positioning with an accuracy of a few meters to a few millimeters depending on the DGPS method used. DGPS utilizing code measurements can provide a relative accuracy of a few meters. DGPS utilizing carrier phase measurements can provide a relative accuracy of a few centimeters. DGPS requires two or more GPS receivers to be recording measurements simultaneously. With two stations recording observations at the same time, GPS processing software can reduce or eliminate "common errors". If one of the stations is a survey control point, DGPS will determine a baseline between the stations and effectively establish the position of the other receiver in the same reference system as the survey control point.

6. Discussion.

a. USCG DGPS Radiobeacon System. One function of the USCG is to provide aids to navigation in all navigable waterways. In the past, Loran-C and Omega systems were used as the primary positioning tools for marine navigation. Today, the USCG is making use of the full coverage from GPS for a more accurate positioning tool for marine navigation. Utilizing DGPS and marine radiobeacon technology, the USCG has designed a real-time positioning system for the coastal areas and Great Lakes regions of the U.S. The USCG has also partnered with USACE to expand this coverage to inland waterways.

(1) General. The system consists of a series of GPS reference stations with know coordinate values based on the North American Datum of 1983 (NAD83) datum. GPS C/A-code pseudorange corrections are computed based on these known coordinate values and transmitted via a marine radiobeacon. A user with a marine radiobeacon receiver and a GPS receiver with the ability to accept and apply pseudorange corrections can obtain a relative accuracy of 0.5-3 meters. This accuracy is dependent on many factors including the design and quality of the user's GPS receiver, distance from the reference station, and the satellite geometry.

(2) Coverage. The system was designed to cover all harbor areas, Great Lakes region and some inland waterways. Each site has a coverage area between 150 to 300 miles, depending on the transmitter power, terrain, and signal interference. In most areas, this provides overlapping coverage. Currently the system covers all U.S. coastal harbor areas, the Mississippi and part of

the Missouri and Ohio Rivers, and the Great Lakes Region. Additional areas within the Midwest U.S. are still under consideration. A map of the coverage area can be found at the NAVCEN web site under the DGPS section.

(3) Availability and Reliability. The system was configured to provide pseudorange corrections with a signal availability of 99.9 percent (in the designed coverage areas) assuming a healthy and completed GPS constellation. To obtain this high availability level, integrity monitors are located at each broadcast site and the system is monitored 24 hours a day by USCG. If a problem with a site is discovered, the user is notified by a message within the information broadcast by that site. Status for each site is also posted on the NAVCEN Homepage. Because of the overlapping coverage of the broadcast sites in most areas, the user should be able switch to another broadcast site without any loss of accuracy.

(4) User Requirements and Equipment. To receive the corrections generated by the reference station, the user needs to have both a MSK Radiobeacon receiver with antenna and a L1 C/A code GPS receiver with antenna. The GPS receiver must be capable of receiving the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) Type 9 messages and applying these corrections to compute a "meter level" position. Some receiver manufacturers have developed a combined MSK radiobeacon and GPS receiver. The costs of radiobeacon receivers range from $500 to $2000. For a combined radiobeacon/GPS receiver, prices range from $2000 to $5000.

(5) Additional Information. Appendix A provides more information on the USCG DGPS Radiobeacon system.

b. CORS System. The CORS Network is a group of GPS reference stations providing pseudorange (C/A code) and carrier (L1/L2) phase measurement data for DGPS post-processing applications. This network is made up of USCG DGPS Radiobeacon sites, USACE sites, National Oceanic and Atmospheric Administration (NOAA) sites, U.S. Park Service sites, other Federal, State, and local government sites and university sites. Future Federal Aviation Administration (FAA) sites will also be included in the CORS network. NGS maintains the CORS system. Data collected at a CORS site is available for a 31-day period via the Internet at www.ngs.noaa.gov/CORS/cors-data.html.

(1) General. The CORS system provides an extra reference station for static positioning with GPS code or carrier phase receivers. For geodetic surveys (using carrier phase), this system provides an inexpensive way to tie a local network into

the national network. For GIS data collection (using code phase and/or where 1-meter accuracy is desired) CORS can be used as the primary reference station, provided a station is within or near (~150 miles) the project area. A map showing the location of the sites can be found on the CORS homepage (http://www.ngs.noaa.gov/CORS). When using CORS as a primary reference or base station for code or carrier phase positioning, it is important to identify the datum that the coordinates are based on for those sites.

(2) Availability. CORS currently operates in an experimental mode and will continue to do so until the network is declared fully operational. The final system is expected to consist of 100-200 stations. At this time, NGS has not implemented full CORS integrity monitoring. NGS will do its best to ensure the reliability of this service, but in the interim, users of the CORS data should be aware that NGS can not guarantee:

-- All current sites will be operational at all times or will be kept as part of the final network configuration;
-- All posted GPS data, positional information, utility software, or ancillary is 100 percent correct and without error; and
-- Any additional proposed sites will remain operational or will be kept as part of the network.

(3) Accessing the Data. To use the CORS network, the user must have Internet access and make sure the post-processing software accepts RINEX 2 data. Data for each site is stored on the CORS homepage for a period of 31 days. Data collected before the 31-day on-line period can be obtained from NGS through a special request. However, this request is limited to no more than 15 days of data for one station per request or equivalent space for several sites. Beyond this amount, NGS may charge a fee for processing the request.

(4) Additional Information. Appendix B provides more information on the CORS system.

7. Proponency and Technical Support. The HQUSACE proponent for this technical letter is Engineering Division, Directorate of Civil Works, ATTN: CECW-EP. Technical assistance may be obtained from the Geospatial Engineering Branch, U.S. Army Topographic Engineering Center, ATTN: CETEC-TD-G, 7701 Telegraph Road, Alexandria, VA 22315-3864, (703) 428-6767.

FOR THE COMMANDER:

CARL F. ENSON, P.E.
Chief, Engineering Division
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2 Appendices
APP A - Additional Information on USCG DGPS Radiobeacon System
APP B - Detailed Information on the CORS System

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Appendix A
ADDITIONAL INFORMATION ON USCG DGPS RADIOBEACON SYSTEM

A-1. Site Set-up and Configuration.

a. Equipment. Each USCG radiobeacon site consists of two GPS L1/L2 geodetic receivers (as reference station receivers) with independent geodetic antennas to provide redundancy and a Marine Radiobeacon transmitter with transmitting antenna. The site is also equipped with two combined L1 GPS / Modulation Shift Key (MSK) receivers which are used as integrity monitors. Each combined receiver utilizes an independent GPS antenna and a MSK near-field passive loop antenna.

b. Site Location. The location of the reference station GPS antennas are known control points within the North American Datum of 1983 (NAD83) and International Terrestrial Reference Frame (ITRF). The geodetic coordinates for these positions were determined by NGS. DGPS corrections are based on measurements made by the reference receiver and the NAD83 known antenna coordinates. These corrections are then transmitted via a marine radiobeacon to all users having the necessary equipment.

c. Data Transmission (data types). The corrections are transmitted using the Type 9-3 (three satellite corrections) message of the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) version 2.1 data format. Other RTCM SC-104 message types transmitted to the user include Type 3 (contains the NAD83 coordinates for the broadcast site), Type 5 (provides information if a GPS satellite is deemed unhealthy), Type 7 (information on adjacent radiobeacons), and Type 16 (alerts the user of any outages). More detailed descriptions of these message types are explained in the Broadcast Standard for the USCG DGPS Navigation Service, COMDTINST M16577.1, April 1993 which can be downloaded from the USCG Navigation Center (NAVCEN) web site (www.navcen.uscg.mil).

(1) Corrections are generated for a maximum of nine satellites tracked by the reference station GPS receiver at an elevation angle of 7.5 degrees or higher above the horizon. Satellites below a 7.5 degree elevation mask are highly susceptible to multipath and spatial decorrelation. If there are more than nine satellites observed at the reference station above 7.5 degrees, than the corrections broadcast are based on the nine satellites with the highest elevation angle.

(2) The sites transmit these corrections at a 100 or 200 baud rate. Since a type 9-3 message is 210 bits (includes header information and corrections for three satellites), the latency of

the data is 2.1 seconds for a site transmitting at 100 baud. For stations transmitting at 200 baud, the latency would be half, 1.05 seconds. The user can expect a latency of 2-5 seconds for all of the corrections for a group of satellites observed at the reference station to reach them. A correction can be considered valid for a period of 10-15 seconds from generation (the USCG limit is 30 seconds). Using corrections beyond this period of time, especially for positioning of a moving platform, may cause spikes in the positional results.

d. Availability of DGPS Corrections and Signal. The system was designed for and operated to maintain a broadcast availability (i.e., transmitting healthy pseudorange corrections) that exceeds 99.7 percent (in designed coverage areas) assuming a healthy and complete GPS constellation. The signal availability, in most areas, will be higher due to the overlap of broadcast stations.

A-2. Integrity of the System. The USCG monitors each site within the entire system for problems or errors 24 hours a day. Each site is equipped with two integrity monitors (i.e. a GPS receiver with a MSK radiobeacon) that are mounted over known positions. The integrity monitors receive the pseudorange corrections from that site and compute a position. The computed or corrected position is compared to the known location to determine if the corrections are within the expected tolerance. The corrected positions calculated by the integrity monitors are sent via phone lines to the control monitoring stations. For the stations east of the Mississippi River, this information is sent to USCG's NAVCEN in Alexandria, Virginia. Sites west of the Mississippi River send their corrected positions to the NAVCEN Detachment in Petaluma, California. Users are notified via the type 16 message of any problems with a radiobeacon site within 10 seconds of an out-of-tolerance condition.

A-3. Coverage. The system was designed to cover all harbors and harbor approach areas and other critical waterways for which USCG provides aids to navigation. Each site has a coverage area between 150 to 300 miles, depending on the transmitter power, terrain, and signal interference. Since the sites utilize an Omni-directional transmitting antenna, some areas have overlapping coverage. Currently the system covers all U.S. coastal harbor areas, the Mississippi and part of the Missouri and Ohio Rivers, and the Great Lakes Region. Additional areas within the Midwest U.S. are still under consideration. A map of the coverage area can be found at the NAVCEN web site under the DGPS section.

A-4. User Requirements and Equipment. To receive and apply the

pseudorange corrections generated by the reference station, the user needs to have a MSK Radiobeacon receiver with antenna and, at a minimum, a L1 C/A code GPS receiver with antenna.

a. The MSK receiver demodulates the signal from the reference station. Most MSK receivers will automatically select the reference station with the strongest signal strength to observe from or allow the user to select a specific reference station. A MSK receiver can be connected to most GPS receivers.

b. The GPS receiver must be capable of accepting RTCM Type 9 messages and applying these corrections to compute a "meter level" position. Since the reference station generates corrections only for satellites above a 7.5 degree elevation, satellites observed by the user's GPS receiver below a 7.5 degree elevation will not be corrected. Some receiver manufacturers have developed a combined MSK radiobeacon and GPS receiver with a combined MSK and GPS antenna.

Appendix B
DETAILED INFORMATION ON THE CORS SYSTEM

B-1. General. The CORS system provides an additional GPS reference station for Geographic Information System (GIS) data collection and geodetic survey applications that do not require real time positioning.

a. GIS Data Collection (Code Phase). GIS data collection refers to applications where 1-3 meter accuracy is desired and code phase GPS receivers are used. For these applications, the CORS system can be used as the primary reference station, depending on the distance from the reference station to the project site. Keeping the distance between the reference station and the project site less than 250 km (~150 miles) should meet the 1-3 meter desired accuracy.

b. Geodetic Surveying (Carrier Phase). Geodetic surveying refers to applications where centimeter accuracy is desired and carrier phase GPS receivers are used. Using the CORS system for geodetic surveying provides an inexpensive way to tie a local network to the national network. It can also be used to provide redundancy or checks for a control survey. However, it should be noted that the NAD83 positions for the CORS sites are based on a different adjustment than most state High Accuracy Reference Networks (HARNs) or High Precision Geodetic Networks (HPGNs).

B-2. Coordinates and Datum Issues. The positions of each CORS site are of the L1 phase center of the GPS antenna. When using CORS as a primary reference or base station for code or carrier phase positioning, it is important to identify the datum that the coordinates are based on for those sites.

a. Coordinates. For each CORS site, the positions are listed in X,Y,Z Cartesian coordinates and latitude, longitude, and ellipsoid height. The latitude, longitude and ellipsoid height are computed from the Cartesian coordinates using the Geographic Reference System of 1980 (GRS80) ellipsoid parameters. There are also two positions listed for each CORS site. One of the positions is based on the International Terrestrial Reference Frame (ITRF) and the other is based on NAD83. The differences between these reference systems can be ~1.5 meters.

b. NAD83. The NAD83 position for the CORS sites are based on the 1996 adjustment of the CORS network noted as NAD83 (1996). In states where a HARN or HPGN has been established, the relative accuracy between a CORS site (NAD83-1996) and a HARN or HPGN site (NAD83-199x) is usually better then 5 cm, but can be up to 10 cm. For states where no HARN has been established, the relative

accuracy between a CORS site (NAD83-1996) and a NAD83(1986) site is usually better than 0.5 meters, but can be up to 1 meter.

c. ITRF. The ITRF position listed at each CORS site is ITRF94 and is based on the epoch date of 1996. ITRF is used mostly for studying plate tectonics and applications related to crustal motion. Unless the project will be referenced to ITRF, do not use these coordinates.

d. Other Datums. For high precision (centimeter-level) surveys, a key issue is to have consistent project control. If there is existing project control, hold these values fixed in the final adjustment, rather than the CORS. Once the positions are in NAD83 or NAD83 HARNs, conversion programs such as CORPSCON (can be downloaded from http://www.tec.army.mil) can be used to convert the final positions from the data processing. Note some conversion programs can introduce errors up to one foot when converting from NAD83 to North American Datum of 1927 (NAD27) in certain geographical areas.

e. Vertical. The vertical component of a CORS site is based on the ellipsoid height. For NAD83-1996 positions, the ellipsoid height listed is based on the GRS80 ellipsoid. For the ITRF positions, the ellipsoid height is based on the ITRF ellipsoid. These ellipsoid heights should not be confused with orthometric heights obtained from spirit leveling. Geoid modeling can be used to convert the ellipsoid heights with the NAD83-1996 positions to North American Vertical Datum of 1988 (NAVD88).

B-3. Data Formats and Sample Rates.

a. Data Format. The data provided from the CORS sites are in Receiver Independent Exchange version 2 (RINEX 2) format. Most, if not all, post-processing software packages accept data in this format. The data for a CORS site is stored in either hourly or daily files, depending on the site setup. The hourly and daily data files are based on UTC time. Both types of files are in a compressed format and need to be decompressed by the GZIP or GZIP386 program. Other ZIP programs might not decompress the files properly. The GZIP386 program can be downloaded from the Software Menu on the CORS homepage.

b. File Naming Convention. The RINEX file naming convention is as follows: {SSSS}{DDD}{H}.{YY}{T}; where SSSS is the four character site identifier, DDD is the day of year, H is a letter which corresponds to an hour long UTC time block, YY is the year and T is the file type. For daily files, the format would be

{SSSS}{DDD}0.{YY}{T}. The letters and hour time blocks are related by:

start hour:	0000	0100	0200	0300	...	2100	2200	2300
letter:	a	b	c	d	...	v	w	x

The file types are as follows:

File type	Ending(T)	Description
Meteorological	m	Meteorological Data
Observation	o	Carrier Phase observations
Navigation	n	Ephemeris Data
Summary	s	Message File

c. Sample Rate or Epoch Interval. The data is collected, for a majority of the sites, at a 30-second epoch interval. A few sites are collected at a 5-second epoch interval. The Readme file on the CORS homepage contains a list of which sites are logging data at 5 or 30 second epoch interval. When using a CORS site for a project, make sure all data or sample rates of the user's GPS receivers are set the same.

(1) For code phase positioning where a 30-second epoch interval is too slow, it is possible to interpolate observational data at faster rates using NGS's INTERPO program. INTERPO will take a standard RINEX-format file as input and generates another RINEX-format file with interpolated GPS satellite observations at a user-specified rate of 25,20,15,10,5 or 1 second. If planning to use interpolated data, the user or rover's GPS receiver should be collecting data at the desired data rate. INTERPO should not be used on GPS data collected by the user.

(2) For carrier phase positioning, INTERPO should not be used. Users may encounter significant problems in use of interpolated carrier phase data.

B-4. Data Availability.

a. On-Line Data. For each CORS site, RINEX 2 data is available over the Internet for a 31-day period. The data can be downloaded off the CORS homepage.

b. Archived Data. Archived data (data collected before the 31-day on-line period) can be obtained from NGS through a special request. However, this request is limited to no more than 15 days of data for one station per request or equivalent space for several sites. Beyond this amount, NGS may charge a fee for processing the request. Data requested is made available for 7 days.

c. Multiple Points per site. Some of the sites (most are also USCG Radiobeacon Sites) within the CORS network contain two points. For example, the Brunswick, Maine site has points bru1 and bru2. Each provides RINEX 2 data.

B-5. Accessing the Data.

a. Before Downloading Data. There are several steps to consider before downloading CORS data. It is important to check the CORS homepage to make sure the desired reference station is up and running. The user's post-processing software must be capable of accepting raw GPS data in RINEX 2 format. If using CORS stations as part of a high precision network and the user's GPS receiver antenna is different from the CORS station's antenna, the post-processing software must be able to accept or account for the phase center offsets in the different antenna types. Mixing of various types or different manufacturer's antennas can cause an error of up to 10 cm in the height component of the GPS baseline solution if not modeled properly. Information about the type of GPS antenna and the phase center offsets for each station's antenna can be found on the NGS CORS homepage.

b. Downloading Data within last 31 days. The data can be downloaded directly through the Data menu on CORS Homepage. The user selects the site, option (type of data: RINEX 2, Coordinates…) and the date for the desired data. Selecting Find_Files button will bring up the ftp directory for the data file(s) for the selection. Sites that log data on a daily basis will only list one data file per site per day. Using the file naming convention from section B-3, select the file or files that span the time desired. Remember that these files are based on UTC time. For each time block there are three files listed, a summary file (contains a "s" in the filename), an observation file (contains a "o" in the filename), and a navigation file (contains a "n" in the filename). Downloading the files to a DOS or Windows computer will drop the ".gz" from the filename.

c. Associated Software. There are three utility software programs are needed to make use of CORS data. They are GZIP386, JOIN24PC and INTERPO. These software programs can be downloaded from the Software Menu on the CORS Homepage.

(1) GZIP386. Since the downloaded files are compressed, they require the program GZIP386 to uncompress these files. Before uncompressing the downloaded files, they have to be renamed so that a "z" is the last letter of the extension. For example, rename filename.95o to filename.oz. To uncompress the files, use the command **gzip386 -d** filename (where the filename is

the observation or navigation file).

(2) JOIN24PC. This program is used to join multiple decompressed hourly observation or navigation files into one session file to be used in the post-processing software. The user must join both the observation files into one file and the navigation files into another file. To join several files together, place all the files with the program into the same directory then type **join24pc 1stfile newfile**. The program will concatenate all the files starting with the **1stfile** and create the file **newfile**.

(3) INTERPO. This program takes a standard RINEX file and generates another RINEX file with interpolated GPS satellite observations at a user-specified rate. This program should only be used for code phase positioning.

d. Archived Data. Data before the 31-day on-line period can be obtained by a special request to NGS through the Data menu on the CORS Homepage. It is important to note that 5-second data is decimated to 30-second data before being archived.

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